COURSE TITLE: ELECTRICAL SYSTEM COMPONENTS

Lesson I: INTRODUCTION TO GENRATION OF ELECTRIC POWER

I.1 Introduction

lectric energy is produced in large quantities at various electric power plants by converting different forms of energy fossil fuels, nuclear energy, water power, etc. Electric energy is transformed by the use of transformers to different voltage levels most suitable for transmission, distribution and consumption. Electric power is transmitted using overhead or cable lines to customers at varied distances from its sources. Electric energy is utilized by various conversion devices such as electric motors, electric ovens, lighting systems, air condition units, etc. The need for power transmission lines arises from the fact that bulk electric power generation is done at electric power plants remote from consumers. However, consumers require small amounts of energy and they are scattered over wide areas. Thus the transmission of energy over a distance offers a number of advantages such as the following:

1. Use of remote energy sources.
2. Reduction of the total power reserve of generations
3. Utilization of the time difference between various time zones when the peak demands are not coincidence.
4. Improved reliability of electric power supply.

The different power stations located in different geographical locations are interconnected by transmission lines thereby forming a power system network usually referred to as the GRID. This chapter presents an overview of the power system structure and principles of power generation.

I.1.1 STRUCTURE OF POWER SYSTEMS

Generating stations, transmission lines and the distribution systems are the main components of an electric power system. Generating stations and a distribution station are connected through transmission lines, which also connect one power

system (grid, area) to another. A distribution system connects all the loads in a particular area to the transmission lines. For economical and technological reasons, individual power systems are organized in the form of electrically connected areas or regional grids (also called power pools). Each area or regional grid operates technically and economically independently, but these are eventually interconnected* to form a national grid (which may even form an international grid) so that each area is contractually tied to other areas in respect to certain generation and scheduling features.

The major advantages of interconnecting power systems include the following:

- **Increased reliability**: In the event of a forced or planned outage of a power station, the affected system can be fed from other stations. River flow, storage facilities, floods, and draughts are the factors that may affect hydrogenation, for example. Outages can easily be met by load transfer once systems are interconnected. Reduction in total installed capacity: In an isolated system reserve units must be maintained separately in power station. However, the reduction in total installed capacity depends on the characteristics of the interconnected system and the desired degree of service reliability.
- **Economic operation**.

I.1.2 Components of electric power systems

There Are 4 Components of Electrical Power System

1. Power system Generation
2. Transmission
3. Distribution

I.2 Power system Generation

Electricity generation is the process of generating electric power from energy. The fundamental principles of electricity generation were discovered during the 1820s and early 1830s by the British scientist Michael Faraday. His basic method is still used today: electricity is generated by the movement of a loop of wire, or disc of copper between the poles of a magnet. For electric utilities, it is the first process in the delivery of electricity to consumers. The other processes, electricity transmission, distribution, and electrical power storage and recovery using pumped-storage methods are normally carried out by the electric power industry. Electricity is most often generated at a power station by electro mechanical generators, primarily driven

by heat engines fueled by chemical combustion or nuclear but also by other means such as the kinetic energy of flowing water and wind. Other energy sources include solar photo voltaic and geothermal power.

There are seven fundamental methods of directly transforming other forms of energy into electrical energy:

- Static electricity, from the physical separation and transport of charge (examples: triboelectric effect and lightning)
- Electromagnetic induction, where an electrical generator, dynamo or alternator transforms kinetic energy (energy of motion) into electricity. This is the most used form for generating electricity and is based on Faraday's law. It can be experimented by simply rotating a magnet within closed loops of a conducting material (e.g. copper wire)
- Electrochemistry, the direct transformation of chemical energy into electricity, as in a battery, fuel cell or nerve impulse
- Photoelectric effect, the transformation of light into electrical energy, as in solar cells
- Thermoelectric effect, the direct conversion of temperature differences to electricity, as in thermocouples, thermopiles, and thermionic converters.
- Piezoelectric effect, from the mechanical strain of electrically anisotropic molecules or crystals. Researchers at the US Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) have developed a piezoelectric generator sufficient to operate a liquid crystal display using thin films of M13 bacteriophage.
- Nuclear transformation, the creation and acceleration of charged particles (examples: betavoltaics or alpha particle emission)
- Static electricity was the first form discovered and investigated, and the electrostatic generator is still used even in modern devices such as the Van de Graaff generator and MHD generators. Charge carriers are separated and physically transported to a position of increased electric potential.
- Almost all commercial electrical generation is done using electromagnetic induction, in which mechanical energy forces an electrical generator to rotate. There are many different methods of developing the mechanical energy, including heat engines, hydro, wind and tidal power.

- The direct conversion of nuclear potential energy to electricity by beta decay is used only on a small scale. In a full-size nuclear power plant, the heat of a nuclear reaction is used to run a heat engine. This drives a generator, which converts mechanical energy into electricity by magnetic induction.
- Most electric generation is driven by heat engines. The combustion of fossil fuels supplies most of the heat to these engines, with a significant fraction from nuclear fission and some from renewable sources. The modern steam turbine (invented by Parsons in 1884) currently generates about 80% of the electric power in the world using a variety of heat sources.

I.2.1 Sources For Generating Electricty

Following types of resources are available for generating electrical energy (No doubt, this list can be extended to include some more up-coming resources. The following list, however, gives the popular and potential resources).

I.2.1.1 Conventional Methods

Thermal (coal, gas, nuclear) and hydro-generations are the main conventional methods of generation of Electrical Energy. These enjoy the advantages of reaching perfections in technologies for these processes. Further, single units rated at large power-outputs can be manufactured along with main components, auxiliaries and switch- gear due to vast experiences during the past century. These are efficient and economical.

These suffer from the disadvantages listed below:

1. The fuels are likely to be depleted in near future, forcing us to conserve them and find alternative resources.
2. Toxic, hazardous fumes and residues pollute the environment.
3. Overall conversion efficiency is poor.
4. Generally, these are located at remote places with respect to main load centres, increasing the transmission costs and reducing the system efficiency.
5. Maintenance costs are high.

Out of these, only two such types will be dealt here, which have a steam turbine working as the prime mover. While remaining two use Internal Combustion Engines (I.C. engines) or Gas turbine as the prime mover, and these will not be dealt with, in this Introductory treatment.

The steam-turbine driven systems are briefly discussed below.

A-Thermal/ Steam Power Stations(Coal-fired)

Thermal energy (from fossil fuels) or Nuclear Energy used for producing steam for turbines which drive the alternators (= rotating a.c. generators).

Chemical energy stored within the coal is finally transformed into Electrical energy through the process of these stations. Heat released by the combustion of coal produces steam in a boiler at elevated temperatures and pressures. It is then passed through steam turbines, which drive the alternator, the output of which is the electrical energy.

This figure below shows a simple schematic diagram of a modern coal-fired thermal station.

Coal is burnt in the boiler. This heat converts water into steam when passed through the boiler tubes. Modern plants have super heaters to raise the temperature and pressure of steam so that plant efficiency is increased. Condenser and cooling tower deal with steam coming out of turbine. Here, maximum heat is extracted from steam (which then takes the form of water) to pre-heat the incoming water and also to recycle the water for its best utilization.

Steam-turbine receives controlled steam from boiler and converts its energy into mechanical energy which drives the 3-ph a. c. generator (=alternator). The alternator delivers electrical energy, at its rated voltage (which may be between 11 to 30 kV). Through a circuit breaker, the step up transformer is supplied. Considering the bulk-power to be transmitted over long distances, the secondary rating

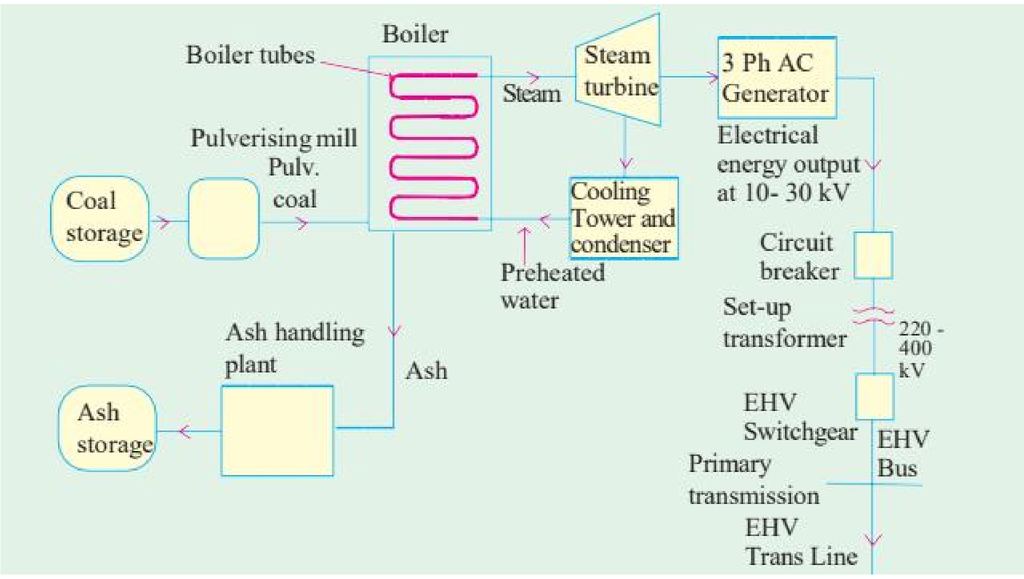

Figure 1: Schematic Diagram of a Coal-fired Thermal Station

A modern coal-fired thermal power station consumes about 10 % of its power for supplying to the Auxiliaries. These are mainly as follows.

(a) Main-exciter for alternator.

(b) Water pumps.

(c) Fans: Forced draught and Induced draught fans for Pre-heaters and Chimney.

(d) Coal handling plant including pulverising mill.

(e) Ash handling plant including Electrolytic Precipitator.

Naturally, whenever such a station is to be brought into operation (either at commissioning or after repairs/maintenance schedule) the power required for the auxiliaries has to be supplied by the grid. Once the system is energized fully, it will look after supplying power to its own auxiliaries.

Merits of Coal-fired thermal stations

1. Fuel (=coal) is cheap.
2. Less initial cost is required.
3. It requires less space.
4. As a combination of all above points, the cost of generating unit of electrical energy is less.

Demerits

1. Atmospheric pollution is considerable.
2. Coal may have to be transported over long distances, in some cases, after some years, and then the energy cost may be quite high.

B-Hydroelectric Generation

Water-reservoir at higher altitudes is a pre-requisite for this purpose. Power-house is located at a lower level. The difference in these two levels is known as "Head."

Based on the "Heads", the Hydroelectric stations are categorized below:

1. Low head up to 60 metres.
2. Medium head between 60 and 300 metres.
3. High heads above 300 metres.

In this method of generation, water from higher height is passed through penstock as controlled in the valve-house, into the water turbine. Thus, potential energy of water stored at higher altitudes is first converted into Kinetic energy. As the water reaches the turbine, it gains speed after losing the Potential energy. Kinetic energy of this

speedy water drives the water turbine, which converts this into mechanical output. It drives the coupled generator, which gives Electrical energy output.

A schematic diagram of such a system is shown in fig.

The valve house has a controlling valve (=main sluice valve) and a protecting valve (= an automatic, isolating, “butterfly” type valve). As is obvious, power control is done by the main sluice valve, while “butterfly” valve comes into action if water flows in opposite direction as a result of a sudden drop in load on the generator. Otherwise, the penstock is subjected to extreme strains and it has a tendency to burst due to pressure of water as a result of sudden load reduction.

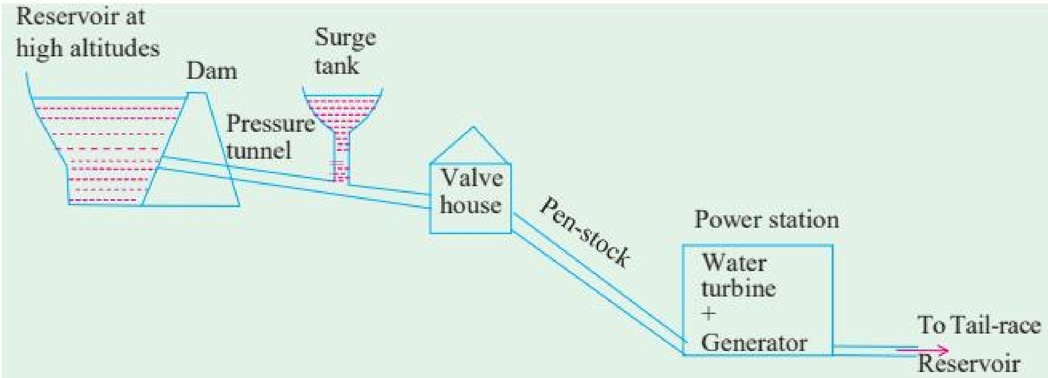

Figure2: Schematic of a typical Hydroelectric station

After doing the work (of imparting its energy to the water turbine), the water is allowed to pass into the tail-race reservoir.

The water turbines are essentially low-speed prime movers. In that, the best operating speed is dependent on the head. Alternators coupled to water turbines thus have large number of poles (since P= 120 f/N). Such alternators have the Salient-Pole type rotor.

There are different types of water turbines suitable for different cases (i.e. Heads, Power rating, Load-variation curve, etc). Since, this is only an elementary treatment, these aspects will not be discussed here.

I.2.1.2 Non-Conventional Methods

Considering the previously discussed thermal methods of conventional energy-generations, it is necessary to understand the non-conventional energy sources, since they have two points in their favour.

(a) Non-polluting processes are used.

(b) Perpetuity and renewability of the main source (which is a natural atmospheric resource) generally exists.

The non-conventional energy sources are further advantageous due to virtually zero running cost, since wind energy or solar energy is the input-source of power.

However, they are disadvantageous due to high initial cost (per MW of installed capacity) and due to uncertainty resulting out of weather changes. For example, dense clouds (or night hours) lead to non-availability of solar energy. Similarly, “still-air” condition means no possibility of wind power generation, and during stormy weathers, wind turbines cannot be kept in operation (due to dangerously high speeds they would attain if kept in operation).

A- Photo voltaic cells

These directly convert solar energy into electrical energy through a chemical action taking place in solar cells. These operate based on the photo-voltaic effect, which develops an emf on absorption of ionizing radiation from Sun.

When ionized solar radiation is incident on a semi-conductor diode, energy conversion can take place with a voltage of 0.5 to 1 volt (d.c.) and a current density of 20-40 mA/cm , depending on the materials used and the conditions of Sunlight. Area of these solar cells decides the current output. An array of large number of such diodes (i.e. Solar cells) results into higher d.c. output voltage.

Since, the final form of electrical energy required is generally an alternating current, it is realized from d.c. using inverters.

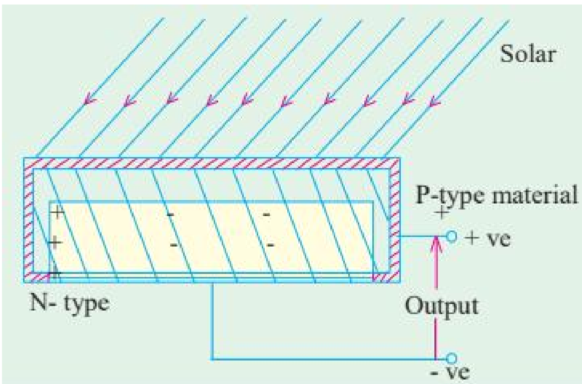

Figure3: Photo Voltaic (or Solar Cell)

Typical materials used for these cells are: material doped with boron, cadmium sulphide, gallium- arsenide, etc. Their choice is mainly decided by conversion efficiency. Best material may lead to the efficiency being typically 15%. Since solar energy is available free of cost, this low-efficiency does not matter.

This method suffers from the disadvantages of having high initial cost and uncertainty (since dependent on weather conditions) including non operative night periods.

Main advantages

(i) no running cost (however, replacements of components may be a botheration),

(ii) no pollution,

(iii) location can be near the load (hence transportation of power is not required over long distances).

(iv) since natural source is involved, it is perpetual.

Individual stations using solar cells are in operation with ratings of the order of 250-1000 kW. With manufacturing costs of semi-conductor devices going down and with the advent of better and better quality of cells which will be available in future, this method of generation has bright prospects.

B- Wind power

High velocities of wind (in some areas) are utilized in driving wind turbines coupled to alternators. Wind power has a main advantage of having zero production cost. The cost of the equipment and the limit of generating-unit-rating is suitable for a particular location (= geographically) are the important constraints. This method has exclusive advantages of being pollution free and renewable. It is available in plentiful quantity, at certain places. It suffers from the disadvantages of its availability being uncertain (since dependent on nature) and the control being complex (since wind-velocity has wide range of variation, as an input, and the output required is at constant voltage and constant frequency). Single large-power units cannot be planned due to techno-economic considerations.

Figure4: Use of Wind Powder

I.3 Cost of Generation

Cost of generation for one unit of electrical energy depends on the method of generation, formulae worked to assess its running cost under the specified conditions, and the cost of transmission line loss to transport power upto the load. These days, a modern utility (= electricity board) has a
large number of generators sharing the responsibility of supplying power to all the customers connected
to the Grid (= common supply-network). Then, for an increase in load-demand, at a known location,
the most economical generating unit is to be identified and that unit should be monitored to meet the increased demand.

I.4 Comparison of Sources of Power

While selecting a method of generating electricity, following factors are taken into account for purposes of comparison:

(a) Initial cost: For a given rating of a unit (in the minds of planners), investment must be known. Naturally, lower the initial cost, better it is.

(b) Running Cost:- To produce a given amount of electrical energy, the cost of conversion process (including proportional cost of maintenance/repairs of the system) has to be known.

(c) Limitations:- Whether a particular resource is available, whether a unit size of required rating is available from a single unit or from an array of large number of units, and whether a particular method of generation is techno-economically viable and is time-proven, are typical queries related to the limitations of the concerned method.

(d) (1) perpetuity, (2) efficiency, (3) reliability, (4) cleanliness and (5) simplicity.

It is naturally desirable that the source must have perpetuity (= be of endless duration), high conversion efficiency, and reliability (in terms of availability in appropriate quantity). The energy conversion must be through a cleaner process (specially from the view- points of toxicity, pollution or any other hazardous side effects). Further, a simpler overall system is always preferred with regards to maintenance/repairs problems and is supposed to be more reliable.